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ELECTRONIC DATA PROCESSING MACHINE REQUIREMENTS

by

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*This paper was prepared while under contract to the Logistics Branch, Office of Naval Research. The object of the paper is to point out from a research perspective some of the more important relationships that affect machine parameters for data processing and for decision-making computations. Certain desirable machine features for data processing are presented.

I. Introduction

In a previous paper [1], the preliminary design of an automatic data handling system for a production control application was presented in block diagram form. The system was the result of a detailed research study at a local manufacturing plant. The need for an automatic system was described; it rests largely on the fact that there are so many individual orders within the production plant at one time that no one man can comprehend which orders are on schedule, behind schedule, and ahead of schedule. Present day production control systems largely decentralize the problem; while a workable system results, there is an evident loss in efficiency. It is believed that the use of electronic data processing systems will help to centralize the production control function and at the same time achieve a greater efficiency.

If there is one unit in the proposed electronic system that stands out in importance, it is the Electronic Data Handling Machine (EDHM). It is this machine similar in design to present day electronic digital computers, that must take over the majority of routine data processing operations, that are being done by clerks in present day systems. Another unit, the Electronic Scheduling Machine, also plays a most important role in the system, by providing information that is impractical to obtain under today's methods, but this unit depends for its operation upon previous data processing by the EDHM. It is felt, therefore, that the EDHM is the basic machine around which the system will be built and is the unit that deserves initial detailed consideration.

An expository account of the proposed production control system was given in [1]. From this account, the major functions that the EDHM would be expected to perform have been extracted and are listed in Table 1. The 18 functions are classified in two ways: by the type of arithmetic or logical operation which the machine must make, and by the system of access to memory. Access to memory has been broken down into two classes, sequential (or systematic) and random, because of the limitations of the magnetic tape units, the major means of bulk information storage. It will be seen that the class of operations covering the most functions in this system is the posting operation with sequential access to memory, with 9 of the 18 functions. Posting with random access to memory accounts for 2 more functions, so that the posting function can be expected to exert a large influence in the choice of a machine for this system.

A complete analysis of machine requirements for all 18 functions is beyond the scope of this paper. From a general consideration, it is desired to point out

	Arithmetic or Logical Operation				Access to Memory	
	Posting	Analysis	Computing	Editing and Punching	Sequential	Random
1. Posting "Requirements" Data	X				X	
2. Posting new S.O. - S. O. Status	X				X	
3. Posting new S.O. "Inventory-On Order"	X				X	
4. Posting Qty. and Due Date in Shop Order	X				X	
5. Posting labor distribution cards	X				X	
6. Posting Route Sheet information from R/S to S.O. status	X				X	
7. Posting On Order to On Hand	X				X	
8. Posting Move Tickets to S.O. status	X					X
9. Posting changes in parts shortages	X					X
10. Posting inspection reports	X				X	
11. Posting unplanned disbursements	X				X	
12. Comparing Shipment Schedule with parts shortages		X			X	

TABLE I

TABLE I Cont'd.

	Arithmetic or Logical Operation				Access to Memory	
	Posting	Analysis	Computing	Editing and Punching	Sequential	Random
13. Comparing Assy. Orders with Inventory		X			X	
14. Comparing Parts Shortages with S.O. Status		X				X
15. Comparing Requirements with Inventory			X		X	
16. Computing expected running times			X		X	
17. Preparing Shipment Schedule cards				X	X	
18. Preparing Back Order cards				X	X	

some of the more important relationships that affect machine parameters, and to this end only one function will be chosen for analysis. However, the same method of attack could be used in analyzing the remaining functions. The function chosen is "Posting Requirements." As can be seen from Table I, this function represents the large class of "Sequential Posting" operations. Also, it has been chosen because it is the least routine of this class of operations, requires more conditional transfers by the machine, has longer unit records, and covers a larger volume of daily operations than the other posting functions.

While this paper has been written with both potential users and producers of this equipment in mind, a small knowledge of electronic computers has been assumed For example, such terms as "command," "three address," and "extract", have not been described or defined, since they are widely used in the vocabulary of electronic computers. Readers not familiar with this vocabulary are referred to [2].

This next section of this paper will deal with systems considerations that affect the EDHM; that is, what type of data handling has been proposed, and reason for the choices. Following this will be a section devoted to a discussion of some desirable features, from a data processing point of view, and then a section dealing with a few considerations of computing requirements for the EDHM. The last section is concerned with some expected future improvements in electronic data handling techniques.

II. System Considerations

At the plant studied, orders are received each day from customers for final assemblies and spare parts made by the plant. The production is of the job shop variety; that is, it is to customer order, rather than to inventory (as in the manufacture of stoves, TV sets, and so on). A large variety of products is possible and only those are produced for which customer orders are received--and for the quantity specified by the customer orders. Thus when an order is received for a final assembly, the Parts List (Bill of Material) for that assembly must be "exploded" to determine what component parts are needed, when they are needed, and in what quantity. A separate record is maintained for all component parts and the new requirements are posted to these records each day. It is this operation which is termed "Posting Requirements."

In the proposed system, described in [1], the program that the EDHM would follow in posting the entries might be:

a) Read one punched card into machine, giving the quantity and date information for one customer order for one component part number. Also on

the card would be the part number and tape address number.

b) Search magnetic tape for the address indicated. When found, read whole record for this part number into the machine. This record consists of the total requirements by month for this part, for a number of months into the future.

c) Add (or subtract, in case of cancellations) the new quantities from the card to the old quantities from the tape. Machine must check to see that the entries are made to the proper months.

d) When all entries have been made, record the new data on the magnetic tape in place of the old.

e) Read the next card into the machine.

f) Continue until all cards have been read and posted.

It will be noticed that this operation is similar to that of filing--inserting a few records into the appropriate places in a larger set of records. It differs from a "combining" operation, such as payroll, where the two sets of records are of the same size and one set is transcribed onto the other--such as entering the number of hours worked into each employees account. Also, it differs from an "analysis" operation where a large set of records is condensed into a few reports.

Important parts of the program have been omitted for the sake of simplicity; for example, the machine must be instructed as to what to do if an error in part numbers is detected, what month to begin posting and when to stop posting.

Several important principles are evident from this simple program:

1) The machine is expected to process one unit record at a time.

2) The length of the unit record depends on the number of months in the future for which it is desired to keep a record, which would vary from company to company and even time to time. It is clear that periodically, obsolete totals can be dropped and new months added.

3) It is likely that the tape addresses desired will not be adjacent on the magnetic tape, and that the tape unit will have to search for the proper address each time.

4) After reading a unit record from the magnetic tape, the tape unit must have the ability to back up again to the beginning of the block and then write the new record on top of the old one when so instructed. (An alternative method is described later in the paper.)

5) If two tape units are used, with the part numbers divided between them to reduce access time, then provision must be made for storing data from two cards within the machine.

6) Rapidity of block location determines the operating speed of the system, so that there should be a good balance in speed between computing speed external access time.

7) The size of the internal memory of the EDHM need not be large for this operation, since the data can be processed from an input buffer register to the arithmetic unit to an output buffer registers without going into the internal memory. Also, the stored program for this operation would not use many internal memory positions.

While almost any general purpose computer with magnetic tape units can be programmed to perform these operations, none of the existing or announced mathematical machines appear to meet all of the requirements well. Some of the limitations of present day machines will be mentioned from time to time in the paper.

The program for posting this card data to magnetic tape would require about 45 to 50 program steps, using a three address machine, and depending upon the particular orders available in the machine. The EDHM proposed in [1] was a magnetic drum machine, for economy and other reasons which will become apparent. With such a machine, a 50 step program would require from 1/2 to 3/4 of a second, again depending upon the particular design of the machine (availability of quick access bands, for example, etc.). A good balance of speed would result if two tape units were used, searching alternately, with average external access time such that the computing unit is kept busy most of the time. Thus the average tape access time should be in the order of 1/2 to 3/4 of a second.

At first, this rapid access requirement on the tape units looks like an imposing obstacle to the system. Many present day tape units use tapes about 1000 feet long, and search at speeds from 30 to 90 inches per second. Using a 60"/sec. speed it will be seen that it takes about 200 seconds (or 3.3 minutes) for the tape to be searched from one end to the other. If the searching is random, on the average it can be expected that only 1/2 this amount of time would be necessary, or 1.66 minutes. This figure is a far cry from the necessary 1/2 or 3/4 of a second.

However, the picture is not quite so dark as it first appears. In the company studied, it was estimated that postings to about 1000 part numbers were required each day, on the average. There is a total of about 7500 active part numbers. If the punched cards representing the input information (see [1], page 56; these are Bill of Material cards) are sorted into ascending part number sequence, then the posting operation is greatly speeded up. Under these conditions, the tape unit must search only 7 1/2 blocks, on the average, before the next part number is found.

To estimate searching time under these conditions the same tape speed of 60"/sec is still assumed, as well as 100 characters per inch of tape, 200 characters per block of information (unit record), and 1/2 inch between blocks for start and stop space. Then, the time required to search the average 7 1/2 blocks turns out to be approximately .300 seconds. To advance just one block would require about .046 seconds, and to advance 12 blocks would take about .456 seconds. Assuming as a rough approximation a Poisson (random) distribution of the number of blocks to be searched before the next part number is located, and an expected value of 7 1/2 blocks, about 95 percent of the postings can be made with a search of 12 blocks or less. Thus, if the 1000 cards are sorted into part number sequence, and if there is a reasonable distribution of part numbers, the tape access time should be in the right order of magnitude.

The necessity of making this part number sort imposes the requirement upon the system of punching the pertinent quantity and due date information into each of the Bill of Material cards before they are sorted out of Bill of Material order. One method of handling this is to have a master card with this information for each assembly ordered. The deck of component parts cards representing an assembly (i.e. a Bill of Material deck) is selected and fed through a gang punch. This punch enters the quantities by due dates in each of the component parts cards with any needed extensions left for the EDHM to perform. The cards can then be sorted out of Bill of Material order and into ascending sequence order, and still retain the needed information.

The reader may wonder why all of this punched card data processing is done, when the same operations can be performed by the EDHM and tape units, and without the cost of 1000 cards per day. The answer is cost and time. A gang punch and sorter together rent for about 1.6¢ per minute, based on a 40 hour week; on the same basis, the EDHM and tape units could be expected to rent for about 40-50¢ per minute. A rough estimate of time involved (based on present day computer design) indicates that it might take the EDHM a maximum of about 40 minutes (expected value: 20 mins.) to make the sort of 1000 items, while the punched card equipment would take about 20 minutes to do the same job, due to the high relative efficiency of punched card equipment for the sorting operation.

Another point to be mentioned is that the tape access time is largely independent of the computing speed of the EDHM, provided that tape reading and writing do not stop computation. Thus it might be expected that the very fast computers would show little or no increase in overall speed, over the slower operating drum machines, for this particular operation.

There has been much discussion in electronic computer circles of late of the advantages of "random access memories." This term applies to those devices where the volume of data stored is quite large and access time is essentially independent of address. One such device under development is reported to have a constant access time of about 2 seconds to any one of one million unit records, of 200 characters each. The value of such a device for large volume data storage is evident. In fact, its use for storing Route Sheet data for the Electronic Scheduling Machine as described in [1], is most appropriate.

For the "Posting Requirements" operation, however, it appears that magnetic tape units may have the advantage, as long as the random access memories have a constant access time of over 1 second, even though the next desired address is adjacent to the last one processed. Because of the sequential nature of the data, and because the expected length of search is so short, the tape units could provide more efficient overall operation.

Should a random access memory be used in this system, it is likely that the sorting operation would be skipped entirely; the punching of the requirements data into cards would be eliminated, also. In this case, allowing 2 1/2 seconds per posting and assuming that the input of Bill of Material data is included in this time, the entire posting time for 1000 entries would be about 40 minutes. This is about the same time required by the proposed system, using cards. Money-wise, it appears that the cost of this operation under the proposed system would be about one-half of that of the random access memory system.

One additional card handling operation, requiring the use of a Collator, could be used to speed up the posting operation if two tape units are used. The part numbers could be divided between the two tape units on an odd-even basis. In the first sorting run on the cards (least significant digit of the part number), the odd and even numbers could be separated, and then the sorting continued on the two piles. One pass through a Collator (requiring 4 to 5 minutes) would then merge these two piles alternately, so that block searching on the tape units would proceed in an alternating fashion. Using the expected value of searching time of .300 seconds (mentioned above), .500 seconds for computing, and .046 seconds each for reading and writing on tape, and .020 seconds to select the tape unit, transfer a block address to the search register, etc., it can be calculated that two entries can be posted in about 1.37 seconds, or all 1000 entries in about 12 minutes. However, reading the punched cards requires about 1 1/2 seconds each

using present-day readers, [Δ] so that it would be this operation that determined the minimum time required for posting.

III. Desirable Machine Features for Data Processing

A suggested logical design for the FDHM itself is beyond the scope of this paper, largely because the subject is so controversial at the present time. For example, machines have been built using one, two, three and four address systems, and each claims superiority in some respects. In addition, pseudo-two and -four address systems have been proposed, where the last address is used conditionally, in case of an overflow; otherwise, the next sequential address in memory is used, as in conventional one- and three- address systems. Some machines use the B-register philosophy, where commands can be modified automatically, making the coding of sub-routines easier. There are many variations of the conditional transfer command, including the comparison of absolute magnitudes, algebraic comparison, equality of two numbers, a switch setting, and so on. All of these variations enter into the logic of the machine to such an extent, and are influenced by the particular application, that the choice of a "general purpose" logical design here would be impractical.

However, there are some machine features that appear to be quite desirable for the application being described in this paper. These features can be classified into the areas of external memory, machine logic, input-output, and reliability; features under each of these areas will be described.

A. External Memory

In the data processing operation under discussion, the major function of the machine is to locate a block of information on the magnetic tape, read it into the machine, perform the necessary computations, and read the corrected record back onto the tape. In designing a machine to perform this operation, then, considerable thought should be given to methods to speed up these simple, repetitive steps. One area of prime importance is that of communication between the FDHM and the tape units.

1) Number of tape units. In the system described in [1], at least four tape units appear to be required. For possible system expansion, the machine should have the facility of adding more tape units. For an even larger

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[Δ] Summary punch card readers, operating at 40 cards per minute, are assumed. Higher speed photoelectric card readers of the future should materially reduce the reading time.

installation, it is likely that over ten tape units would be needed, although the newer random access memories may prove suitable here.

2) Independent search, two or more tape units. As has been mentioned, the use of two tape units in "Posting Requirements" would materially speed up this operation. To use two tape units efficiently requires that they be able to search independently of what else is going on in the machine--while a block of information is being processed from one tape, for instance the other tape unit is searching for the next block to be processed. It is likely, in fact, that the two units would at times be searching simultaneously.

Also, it should be mentioned that the ability of searching for two or more sets of data simultaneously should be considered even for the newer random access memories. There will be cases where the constant access time of one or two seconds is too long for efficient processing, if only one set of data can be acquired at one time. It is realized, however, that this requirement may greatly add to the complexity of the random access memory system.

It is to be expected that management will often call for new reports, the data for which has not been filed systematically on the tape; it is known that the information is on the tapes but not known where on the tapes it might be. In this case, the machine must search for the information by other than the block number on the tape. Independent search by two or more tape units for information stored within the block, rather than by block address, implies the need for each tape unit to have the ability to extract words from the blocks, compare with the control number in the search register, and branch, depending upon the outcome of this comparison. Some will argue that these requirements will greatly increase the cost and complexity of the tape units, so that it would be better for the EDPM to do the extract, compare, and branch operations. This brings us back to searching by one tape unit at a time, of course. The choice depends on how often this "analysis" type of operation (see page 6) must be performed in the particular firm. If required frequently, then independent search by several tape units can well be considered. Also, if the quantity of records to be analyzed is large, searching by one tape unit at a time may not be feasible; this applies even more strongly to random access memories. To analyze one-half million records, at 2 1/2 seconds each, would require about 350 hours of machine operation, for example.

3) Automatic read-in to buffer. Another means of speeding up the communication is to provide automatic read-in to a buffer register, once the desired unit record has been found. This feature means that the information will be available to the machine at the high internal speed when it is called for, but probably will

require a separate buffer register for each tape unit. (Some of the faster present day machines use only one buffer for all tape units, because of their high speed of "putting away" the data into internal memory.) The usual machine design is to provide only one buffer; the block search operation simply locates the desired block and does not read it. Finally, when the information is desired, a "tape read" instruction must be given, whereupon the block is read into the buffer, normally at a speed materially slower than the internal computing speed of the machine.

4) Input and output to tape unit does not interfere with computing. Obviously, reading information in to and out of a buffer should not interfere with the computing operations of the machine, because this is the type of operation that will be most common in data processing. Many present day machines use one of the computing registers as a high speed input-output buffer. For example, the quick access loop in a magnetic drum machine or the multiplier-quotient register in an electrostatic tube machine have been used for this purpose. While such a design either partially or completely ties up computing during the input-output operation, this limitation is not so stringent on mathematical machines where the amount of input-output is usually small compared to the amount of information being processed within the machine. In the design of the EDHM, however, the volume of input-output makes independent buffers almost a necessity.

5) Tape unit signals when operation completed. After the desired unit record has been located on the tape, and read in to the input buffer, the EDHM should be notified that the search has been completed on that particular tape unit and the data is available for use. This signal would also prohibit the EDHM from trying to obtain the data from the input buffer when the tape unit was still in the process of transferring to the buffer.

When the instructions are given to record the modified requirements data back on to the tape, the tape unit can also be given the address of the next unit record. It can then proceed with the search as soon as the recording has taken place.

6) Read and write on tape as subsequent operations. As can be seen from the "Posting Requirements" operation, the machine reads a unit record from the tape, processes it, and then records the new unit record in place of the old one. In fact, it can be visualized that in some cases only a part of a unit record need be processed, (as in posting labor distribution records on the Shop Order Status tape) and it would be desirable to insert it back into its proper place in the unit record without rewriting the whole record. The method of tape recording

should be amenable to this type of operation. This feature is mentioned because some important present-day machines do not provide it.

7) Ability of preparing magnetic tapes externally to EDHM. It is very likely that it will be desired to prepare or use magnetic tapes without tying up the EDHM. Some present day computers, for example, have separate tape preparation units and output printer units; this allows these lower speed operations to be performed without slowing down the computer itself. It follows that the tapes themselves should be easily re vable.

8) Ability to work with Random Access Memories. Most of the discussion on external memory so far has been concerned with magnetic tapes. In any machine built for a wide commercial market, however, it is very important for the machine to be compatible with the newer random access memories, as these promise to be powerful building blocks for many system designs. For one thing, six decimal digits will be needed to designate the address of one million records, and the EDHM design should meet such a requirement.

B. Machine Logic

1) Several special commands. As was previously mentioned, one common operation will be that of backing up the tape one block, or one unit record, so that the new data can be written in the place of the old. It may be desirable, therefore, to include a command to "back up one block" in the repertoire of commands, to make this operation as efficient as possible. In fact, it would be possible to make the operation automatic, to occur after every tape reading, unless an inhibiting signal is programmed as would be the case in "analysis" operations. It should be mentioned that there is at least one other possible solution to this problem: instead of backing up the tape and writing the new information in the forward direction, simply run the tape backward and read the digits out in the reverse order. This method is being used in at least one present day computing system. This solution, however, may present difficulties when only a part of a unit record is being inserted, plus the fact that the tape unit is left standing one block farther away from the next desired address.

Another important command, included in some present day machines, is that of "equality sensing." From the "Posting Requirements" application, it can be seen that one common function would be comparing part numbers from the card and from the tape, to see that they agree. Similarly, the machine would compare dates to determine which month to post the entry to. The machine must therefore be able to sense equality between two numbers. If they are the same, one course of action

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would be taken; if not, another course. This command obviously is one form of the important conditional transfer type of command. While it can be programmed as two conditional transfers of other types, it will probably be used to such a great extent that a single command would be warranted.

Another type of special command that should be considered would be that of sorting and/or collating. While these functions may be used less in electronic machines than in punched card machines (especially with the advent of random access memories), it is likely that they will still be used to a large extent. Sorting and collating are related operations; indeed, one way of accomplishing sorting is by a collation operation. Present day mathematical machines are relatively inefficient at these operations, compared to punched card machines. In a commercial machine, the collation operation could be built in, and activated by a special command, in order to improve the efficiency of the operation. Such a built-in command would imply some additional features added to the arithmetic unit of the machine; some work along this line, which cannot be described here, has been carried on by the author. Another solution, of course, is to do most of the sorting and collating by punched cards when possible, as is the case in the proposed system.

Another type of conditional transfer command that would be most useful might be called the "sense" or "test switch" operation. For example, every few seconds the EDHM would stop whatever it was doing and check to see if a move ticket has been inserted into the reader, in the system described in [1]. If a move ticket has been inserted, its signal would cause the EDHM to switch over in its program to process the move ticket. If no move ticket is in the reader, the EDHM would proceed with whatever it was doing. Another application was mentioned previously, that of checking to see if a desired block has been located by the tape unit.

2) Word and block lengths. One of the major problems of an electronic business machine will be the efficient storage of data--e.g. how much of the available storage medium can be used for storing information and how much must be lost due to inflexibility of the system. In punched cards with 80 or 90 columns, for example, the same number of cards will be used whether 40 columns of data are recorded in each or 80 columns of data--although one deck of cards would contain twice as much data as the other. In electronic machines, it is believed that the situation can become more serious. If a given file of data exceeds the capacity of one tape, due to such inflexibility, it is probably not just a matter of another reel of tape but also of a second tape unit that must be used, in order to provide machine access to each.

One way in which such flexibility can arise is from fixed word and block lengths. If most numbers are only three decimal digits long, but a fixed word length of 6 digits is provided to cover the worst case, then much of the storage medium will be wasted. One way around this is to put two numbers in the same word, and then separate them when needed by means of the extract code. This is still not a complete solution, requiring additional machine time, which is a point to consider since it is a common operation that the machine must perform very often. Similarly in block lengths, if many of the unit records are some 60 decimal digits in length (as is the case with much of the data listed in Table I), but the machine records data basically in blocks of, say, 200 or 500 digits, the same type of problem arises. Indeed, within a single firm, there will be a variety of unit record lengths.

Punched card machines have partially attacked these problems by means of plugboards, whereby number lengths (fields in the card) can be selected for different types of data within the plant. Block (card) lengths have been relatively inflexible, however. Present day mathematical machines have largely ignored the problems, since mathematical number lengths tend to be more uniform and often approach the maximum precision of the machine.

Future business machines may well solve these problems by the judicious use of automatic extract techniques, which could break up the data into proper fields as it is being read off of the magnetic tape, and put into separate word spaces in the input buffer register. An extract code for each type of data could be prepared and stored within the machine (comparable with different plugboards on punched card machines) and the proper one called into use when needed. This could provide optimum word lengths and block lengths for each type of data, and the quantity of blank storage spaces would be greatly reduced. From a machine design standpoint, this technique imposes problems of reliable indexing, more circuitry in the tape units, and resultant higher cost. Indexing might be achieved by a symbolizing "tag" that preceded each unit record on the tape, which would put the machine "in step" and could identify the extract code to be used.

3) Internal memory. It has been pointed out previously that the number of program steps involved in any data processing operation probably will not be large. It is estimated that very few would exceed 50 to 100 three-address program steps. Also, it is unlikely that very many such programs would have to be stored internally at one time; rather, they would be called in from external memory when needed. One exception might be the processing of Move Tickets, which could occur at random throughout the day in the system described in (A). Also, very little data

would be stored internally; the unit record being worked on can be transferred from the input-output buffer to the arithmetic unit and thence back to the same buffer, and would therefore require no internal memory positions. In the analysis of data, (such as the volume of shop orders and loading schedule by department) the accumulated totals for each classification would be developed in internal memory. (Incidentally, this indicates how electronic machines would not be so dependent upon the sorting principle as are punched card machines.[Δ]) It would seem, therefore, that internal memories in the order of 500 to 1000 words would be adequate for most applications.

4) Arithmetic unit. Most present day machines have three registers in the arithmetic unit, one of which (the accumulator) generates most of the answers within the machine. This arithmetic unit is then time shared in order to perform the operations called for in the program, in a serial fashion. In commercial machines, it may be found desirable to provide several additional units within the arithmetic unit. For example, multiple units to perform compare and branch operations might greatly speed up certain data processing operations of the "selection" type, by providing parallel operations on the data. Such modifications to the arithmetic unit would depend, of course, on the type of data processing being considered.

5) Flexibility. One of the proposed methods of approaching the commercial data processing machine problem is by the use of the "building block" technique, where any given installation would be composed of a selection of available components to meet the particular requirements. This is the philosophy that has been followed by the manufacturers of punched card equipment, with considerable success. It has a number of advantages, such being an expandable system that can meet the requirements of different size businesses, good reliability because normally the breakdown of one component does not stop the whole system, and improvement because the components can be improved and replaced individually without requiring that the whole system be changed.

It should be noted that there is quite a bit of controversy about this point. The other major approach to the problem is to provide a fast general-purpose machine that can perform all of the functions of data processing. Since a new program can be inserted in a matter of seconds, the machine can be switched from the processing of one type of data to another many times a day. Since only one machine is used, economy should result from the lower manufacturing costs of the

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[Δ] I am indebted for this point to Mr. David Kenner, of Computer Research Corporation.

standardized machine, less repetition of equipment (since some of the parts of each component will be the same), and perhaps less operator costs.

For the purpose of this paper, however, it will be assumed that the "building block" approach is the one followed. One point to consider, then, is the ability to switch building blocks easily. In punched card equipment, for example, the operator can switch from one collator to another (should the first one break down) simply by changing plug boards. In an electronic machine with a stored program, all pertinent addresses may have to be changed automatically so that the new unit can take over the functions of the old one. It is possible, of course, that even this step might be eliminated by simply throwing switches to connect the new unit in place of the old one.

C. Input-Output

Much has already been written about the need for improved input-output equipment, for the commercial application of electronic computing machines. At the present time, the insertion of data into the machines and the extraction of results constitute two of the major bottlenecks in data processing systems. For the EDHM, several comments are in order on this phase of the requirements.

1) Number system. It seems most desirable for the EDHM to accept standard decimal information, with no scale factoring of the numbers required by the operator or programmer, similar to the way present day desk calculators work. There should be no loss of computing time due to the use of these decimal numbers, nor should there by any limitations imposed upon input-output equipment or external memory equipment due to the fact that decimal numbers are used. In other words, the number system used within the machine is not determined by these requirements; it might be binary, binary-coded decimal, bi-quinary, or other, as long as it meets the input-output and other user requirements.

Similarly, it appears most desirable for the machine to handle alphabetic information on input-output, with no loss in computing time due to code conversion, or the need for table look-up of alpha-numeric part numbers, to get the machine code equivalent. Since alphabetic sorting and collation will be necessary, the alphabetic coding within the machine should be consistent with these requirements.

2) Types of inputs. It is believed by the author that punched cards will remain one of the important mediums of electronic data handling systems for some time to come, especially where much communication between the machine and humans is called for. They are well developed, reliable, cheap, and easily expandable by

the use of more cards. Also, the same card can be read by a human or by a machine and thus provides a good medium where both types of reading must take place. An example of this is the Move Tickets described in [1]; the printing on them is used to move the shop orders to the right departments, and the punched holes are read by the machine to keep the Shop Order Status tape up to date. The point is controversial, however, in that some believe that overall efficiency will be gained by going to electronic storage almost completely. Also, the use of a magnetic card has been proposed.

One of the important principles in automatic data handling is to eliminate as many manual operations as practical. Pre-punched cards are one method of doing this; the use of mark-sensing to enter new information can also be considered.

Some types of data can be picked up even more directly, by having appropriate pick-ups at the machine tools themselves, and electrically transmitting the information to the EDPM. More investigation along this line will be carried on by the Management Sciences Research Project.

It appears that regular typing operations will be essential at several points within the firm, at least for some time to come. The use of typewriters that produce a punched paper tape as well as the typed copy should be most useful, in that the punched tape will provide the information in machine language at no additional effort. "Programming" of such typewriters, to punch only the desired information into the tape, is being provided in some newer machines.

It is evident that the input and output buffer registers should handle the variety of word and block lengths required by the data, as has been discussed previously with respect to the external memory.

[illegible] will probably be a desirable feature. Present day punched card readers, for example, often operate too slowly for efficient data processing. Older summary punches, which have been used as card readers will read 100 cards per minute when operating "free running" but their speed is reduced to about 40 cards per minute when "slaved" to another piece of equipment. At least one present day computer has made use of a collator input, running at about 240 cards per minute. It should be noted that the input reader should be under the control of the computer, with input information being called for on a card-by-card basis as needed by the computer. However, in all these cases, an expensive punched card machine is being used merely as a card reader; it is believed that a cheaper higher speed device designed for this particular operation could be made available.

3) Types of outputs. Three types of outputs appear to be of primary importance: printed, punched card or punched tape, and direct visual.

The printed output can be directly connected to the EDHM, or by way of punched tape, punched card, or magnetic tape. Low speed printers, such as electric typewriters or teletype units, can meet the format requirements of business forms and reports, but would seriously slow up the system if connected directly to the EDHM. New high speed printers provide better balance with computing speed, but are so far designed for continuous paper feed, rather than the type of paper motion called for in printing invoices or pay checks. It appears, then, that the printer probably should not be connected directly to the machine.

Punched tapes and/or punched cards would provide a means of obtaining printed output on a separate printer. For high speed printers, magnetic tape might be used in the future, also; for today, the punched card tabulators provide quite an efficient means of printing many types of business forms, and tape controlled typewriters provide a low cost form of printer.

Also, punched tape provides a relatively cheap, compact means for the long term storage of information, where it may be desired to read it back into the machine at a future time. Conventional punched cards can be used for the same purpose, but require greater storage space for the same amount of data; however, a new punched card system recently announced would require only about one-half the volume of conventional size cards.

One important type of output, largely unexplored so far, is a direct control panel where the information is presented in some graphical manner. In the system described in [1], for example, the Production Controller wants to scan quickly a mass of data and then concentrate on certain critical items. Pages of printed numbers are not easily scanned, but a "pictorial" display is, where relationships are stressed rather than values. Since no such control board is yet known to the author, these EDHM requirements have not been considered to any great extent yet.

D. Reliability

Most discussions on the subject of electronic data handling systems for business agree that the machine must be highly reliable--but seldom is the discussion carried beyond this point. "Reliability" can include several factors, among them:

a) The detection (and possible automatic correction) of random transmission errors, to a very high degree of probability;
b) The detection of computation errors;
c) Satisfactory operation of the machine during scheduled working hours, over long periods of time, under normal environmental conditions.

From a realistic standpoint, the discussion should also include the relative reliability of the electronic machine versus the present system (manual or punched card)[A]. Unfortunately, the measurements of the latter are seldom made.

1) Detection of transmission errors. Several methods have been proposed and used for the detection of transmission errors within an electronic system. A simple parity check [3] would detect the large majority of transmission errors through the use of redundancy in the code; with a somewhat more redundant code, some of the errors could even be automatically corrected. One machine [4] uses a transfer weighted count to detect possible multiple errors on the same word, during transmission. And another technique that has been used is the coding of information in a bi-quinary form where all numbers have only two out of seven bit positions in the "on" state.

2) Detection of computation errors. One method of detecting computation errors is to perform parallel computations in two arithmetic units within the machine, and compare results. This method is used by at least one major type of computer today. Another method, requiring somewhat less equipment, is the use of the arithmetic weighted count [4], where the same arithmetic operations are performed on smaller check numbers as on the operands themselves.

It is believed that time will be of the essence in the use of these machines, so that serial computations in the same arithmetic organ to check answers would not be tolerated for long. It should be mentioned, also, that in case of a discrepancy between the answers in a "double check" system, the correct answer is not indicated, but only an error is indicated. The use of a "two out of three" technique has been suggested by some as a scheme for automatically correcting computation errors. However, many of the errors in transmission and computation are of the "transient," or random, variety. They are most probably due to "noise" in the machine, rather than to the consistent failure of one of the components. In order to correct these errors, it is usually sufficient to transmit the number once again, or perform the computation a second time. Some present day machines have the facility built into them of automatically reworking a step in which an error is detected. This appears to be a very valuable advantage in the use of the machine. Other machines, which have only the facility of error detection would stop after detecting such an error, and require either that the operator take appropriate action to see that the step is reworked, or in some manner call a previously programmed remedial sub-routine into operation.

[A] I am indebted for this point to Mr. W.L. Sparks of Northrop Aircraft, Inc.

Another desirable feature, found in some present day machines, is "automatic test for overflow". At any step of the computation, if an answer exceeds the allowable limits of the machine, this error should be detected immediately and the machine stopped. Some machines provide a test for overflow as a programmed operation; this version of the "fail safe" philosophy, however, calls for an automatic test and stopping the machine, unless the coder knows that an overflow can occur at that step and has instructed the machine what to do in case of an overflow. This test is especially important when variable word lengths are used, as mentioned on page 17, where it might be possible for totals to run over into the next word, resulting in meaningless data.

In long mathematical problems, computation errors can often be uncovered by the use of programmed checks; after the roots of an equation are determined, for example, they would be substituted back into the equation to see if the equation is satisfied. In data processing, such programmed checks will be more difficult to incorporate, since each piece of data is largely independent of the other data. Simple checks might be used, such as adding two numbers, and then subtracting one of them from the sum to see if the other number is obtained.

3) Satisfactory operation over long periods of time. From the point of view of satisfactory operation over long periods of time, much valuable experience is being gained on existing mathematical machines. A tabulation of reported results has been given in Table II.

In general, magnetic drum machines appear to be making the best overall showing at the present time, with delay line machines running a close second. It is hard to make a valid comparison, however, because of the difference in computing speeds. In very large volume data processing applications, the overall reliability of several lower speed drum machines might well be lower than the reliability of a single delay line or electrostatic tube machine. In the "Posting Requirements" application described herein, a magnetic drum machine has been selected, for reasons of economy, reliability, and balance between computing time and external access time. In a much larger installation, the factors may well be balanced toward one of the other types of machines. For example, while an electrostatic storage tube machine may cost about ten times as much as a magnetic drum machine, its computing speed (multiplication time) is roughly twenty times as fast. Future machines, using magnetic cores for internal storage may well combine the advantage of high speed and high reliability.

Reported Computer Reliability

(Satisfactory operation hours as percentage of total available hours)

I Magnetic Drum Machines

- A. Burrough's machine - 83-85 percent for 2 to 9 months; (2) and (5)
- B. Harvard Mark III - 82 percent for 4 weeks; (4)
- C. ERA 1101 - 96 percent for 4500 hours; ([illegible])

II Electrostatic Tube Machines

- A. Whirlwind (own tubes-1024 bits) - 85 percent for 3 months at 99 hours per week; (3)
- B. ORDVAC (Williams-1024 bits) - 66 percent at 145 hours per week; (4
- C. IAS (Williams) - 54 percent at 90 hours per week; (4)
- D. SWAC (Williams-256 bits) - 65 percent at 2 shifts per day; (4)

III Delay Line Machine

- A. SEAC - 75 percent for 6 months at 168 hours per week; ([illegible])
- B. UNIVAC - 72-80 percent for 20 computer months at 168 hours per week; (6)

Data References for this table:

(1) ONR Digital Computer Newsletter, April 1951
(2) ONR Digital Computer Newsletter, July 1951
(3) ONR Digital Computer Newsletter, October 1952
(4) ONR Digital Computer Newsletter, April 1953
(5) "Review of Electronic Digital Computer, AIEE, February 1952
(6) Transactions of the IRE, PGEC, December 1952

TABLE II

Experience with mathematical machines has indicated that a program of preventive maintenance is most helpful in extending the length of the periods of satisfactory operation. Within this field of preventive maintenance, there are two main schools of thought. One school teaches that tubes and other critical components should be removed periodically, tested, and results entered in a log. When it is seen that a component is falling below a certain point in performance, it is replaced. The other school goes under the names of "marginal testing". This method calls for changing some critical voltages during the testing of the machine. Components that are on the borderline of failing under normal conditions will be caused to fail when subjected to these abnormal conditions, and can be removed. The machine is then assumed to be ready for operation.

While there is as yet no clear cut indication of which method is superior, the author's preference is for marginal checking. It is believed that the best way to test a component is under the actual conditions in which it is supposed to work, and not in some separate test unit. When components are removed for testing, they are often put back in the machine incorrectly; this is most noticeable in the case of crystal diodes. Of course, such mistakes should be correctable with the training of maintenance personnel. In a large scale machine, the incorporation of marginal checking facilities can cause considerable additional expense; in fact, in these machines where some characteristic is very critical, it may not be possible to incorporate this feature. Where it can be used, though, it should prove to be most helpful in extending the amount of machine operating time.

Reliable operation with magnetic tapes has not yet been firmly established. In the past, tapes have been found to have a large number of areas on which information did not record properly. When read back, therefore, incorrect information would be obtained. Fortunately, the manufacturers of magnetic tapes have improved their product greatly, to the point where such spots have been largely eliminated. Computer engineers have developed methods for detecting the remaining few such spots on a tape, and avoiding them.

The possibility of tape breakage will also be greatly reduced with the advent of a new plastic, called "Milar," as the tape base. Production quantities of this new type of tape are expected in about two years.

Dust particles on the tapes still must be considered a problem, since they cause the tape to be pushed away from the reading heads, with a resultant loss in information. Dust covers and other such protective measures should greatly reduce this problem, however. Based on these developments, it is the author's belief that magnetic tapes will prove to be a reliable medium of data storage for business and industry [5].

Another problem in reliability is the fact that expensive electronic data processing machines will be economically feasible mainly from their value as centralized records devices--the consolidation of production control and accounting records for example. To perform the necessary data processing on a time sharing basis, the internal speeds and complexity will probably go up, and as these factors increase, so will the likelihood of equipment failure.[Δ] One possible solution to this problem is the use of the building block technique, discussed previously, whereby breakdowns can be localized without stopping all data processing.

IV. Considerations of Machine Features for Computing

The discussion of the EDPM so far has been concerned with its application to data processing, where a few computations are carried out on a large volume of unit records. This type of use will arise, for instance, in plants now having a large amount of paper work in the control of production. The operations will be routine in nature, such as recording the movement of a parts order from one operation to the next, the receipt of a parts order into the stock room, or the disbursement of parts to an assembly order.

One of the promising applications for electronic computing machines, however, is in the field of decision-making, or as an aid in decision-making. Much of the work of the Management Sciences Research Project is concerned with the formulation of mathematical models of certain production decision problems, in plants where the "freedom of choice" in decisions is great. In [1], several models of varying computational complexity are presented for the loading and scheduling functions. The design of an EDPM could well consider the requirements that will be imposed by such mathematical models. Since the models are still under intensive analysis, to obtain improved mathematical methods of computation, it is still too early to discuss very many specific requirements that they will impose upon the EDPM.

One mathematical model, discussed in [1], has received detailed consideration by several groups throughout the country. This model is called Linear Programming (LP), or programming interdependent activities. It was originally developed by Dr. G. B. Dantzig, for the solution of optimum programs for the U.S. Air Force. Since then, it has been applied to other problems by other groups; for example, see [6].

In [1], it was pointed out that LP bears a resemblance to the loading problem in a production plant, once certain "non-overlapping" restrictions have been relaxed. In a reasonable sized production application, the LP model would consist o

[Δ]I am indebted to Mr. John Haanstra of IBM for this point.

a large matrix of numbers with perhaps several hundred rows and columns, or more, representing product requirements, standard hours of production, inventory quantities, available machine hours, and time periods. The problem is to determine the quantities in which to produce the products in the time periods specified, so as to maximise profit or meet some other condition such as optimum use of facilities. Dr. Dantzig, now at the RAND Corporation, has developed a method for the solution of large LP problems, called the "simplex" technique [7], and has also considered computing machine aspects for such problems [8].[Δ]

[Δ]During an informal discussion with Dr. Dantzig, he stated that as a rough rule of thumb, in the worst case a programmer would desire an internal machine memory with twice as many words capacity as there are equations in the problem. Present programming calls for providing for two vectors at one time in the memory, holding one fixed while developing the other. Other vectors are called in from external memory as needed.

Also, to estimate computation time, Dr. Dantzig felt that the number of multiplications, x, would most likely fall between the limits:

$$Km^2nT \leq x \leq Km^2nT^3$$

where K = an integer in the range of 1 to 4, indicating the degree of skill in programming and coding the problem, etc.,

m = number of equations (rows in matrix),

n = number of items (columns in matrix),

T = number of time periods.

(As an example, assume a problem where $m = 250$, $n = 500$, $T = 3$; in the best case, let $K = 1$ and in the worst case let $K = 4$. The number of multiplications then would most likely lie between 93,750,000 and 3,375,000,000. Since multiplication time is a good estimate of total computation time, the time required for two of the more common types of present day electronic computers would be, under present machine designs and coding methods:

	Av. No. Mults/sec	Est. Problem Time	
		Hrs. (min)	Hrs (max)
Magnetic drum machine	120	218	7800
Electrostatic tube machine	2000	13	470

Thus while computation time of an electrostatic tube machine might be of a reasonable order of magnitude in the best case, further work is desirable to reduce computing time, especially for magnetic drum machine applications.)

Dr. Dantzig thought that it was likely that computing time could and would be reduced materially below the maximum given above.

The solution of LP problems on a UNIVAC computer has been accomplished by the U. S. Air Force, under Project SCOOP. Based on this UNIVAC experience, the Air Force is considering machine requirements for a computer capable of handling larger LP problems. Some of this work is being carried on in conjunction with the electronic computer development group at the National Bureau of Standards.

In addition to the loading problem, a restricted scheduling model was discussed in [1]. This model provides a method of systematically improving a schedule by an iterative procedure through the use of priority numbers and penalty constants. It has not yet been determined how much of the problem would be handled on the Electronic Scheduling Machine and how much on the EDHM. This is an area that is being ivestigated further under the Management Sciences Research Project.

Since the decision-making models often are not too clearly in mind yet, a practical approach appears to be to use present day machine capabilities to their limit, instead of waiting for the optimum machine.

V. Future Expectations

The EDHM, as discussed so far in this paper, bears a great resemblance to present day mathematical machines in its construction and logic. This has been done purposely because it is believed that the first commercial machines will follow this approach, for reasons of economy and reliability. At the same time, much advanced thinking is being carried on throughout the country, on improved designs for computers. Such advances will undoubtedly affect the development of EDHM's. It is desired, therefore, to mention a few of these proposed improvements (some almost of a science fiction nature) and their likely impact on EDHM design.

1) Central Records Machine. The trend in thinking in the electronic data processing field is in the direction of a central records machine, that handles all of the paper work of a firm, as opposed to a production control machine, accounting machine, etc. Centralization has many apparent advantages; especially from the fact that decisions can be based on the "picture as a whole" rather than on just part of the picture. The use of such a machine implies several needed developments, however:

a) Higher speed. Since the machine will be time-shared between all departments of a plant or a firm, higher speed of operation will be needed. Internal access time of present day drum machines is, on the average, about 5 milliseconds; for delay time machines, about 150 microseconds; and for electrostatic tube machines in the order of 5 to 20 microseconds. Developments in magnetic cores and ferroelectric sheets show promise of access times in the order of one-tenth of a

microsecond would imply an external read-in time for sequential records in the order of 1 millisecond per complete unit record.

b) Equivalent of many internally stored programs. The machine will probably be interrogated at random times throughout the working day by the various departments. As soon as a circuit is set up between the machine and the department, the machine must decide which of its programs it must use to process the particular type of data involved. Developments in self-programming techniques may be helpful here, where the machine follows a systematic analysis of the data until it determines which program is required.[Δ]

c) Interpreting human questions. Humans in the plant will unquestionably ask the machine for certain data throughout the day. Some have suggested a "dialing" system similar to telephones for this application. In order to avoid the necessity of coding all questions in numerical form, a limited vocabulary "keyboard" may be desired, which would give the humans less difficulty in phrasing their questions.

d) Automatic reading of paper records. When customer orders are received, for example, it would be desirable to read them directly into the machine for processing. Developments are under way on devices which can read standard form decimal numbers from a printed page, directly into electrical signals. Since customer order forms are of various sizes and shapes, a stencil overlay might be prepared for each customer, with something like a color code to tell the machine what piece of information is where. And the machine would become even more complex when it had to know the equivalence of dates written as "April 3, 1956 and "4/3/56

First steps toward automatic reading have been in the form of mark sensing on punched cards, and position sensing on census enumerator data sheets, [9].

e) Random access memories. Present trends in the development of large scale random access memory systems appear to be in the direction of a single read-write head unit that is moved to the area of the memory specified in the program. Access time is in the order of 1 to 2 seconds. As has been discussed previously, such characteristic certainly are not optimum, from a data processing point of view, but they represent a big improvement over random access from magnetic tapes.

[Δ] Mention should be made of Claude Shannon's mechanical mouse, developed at the Bell Telephone Laboratories. The "mouse" follows a systematic procedure in solving a maze, remembering correct paths. On subsequent trials, as soon as it comes across and recognizes the correct path, it then follows this path directly to the "cheese."

It may be some time before a decidedly different approach to the problem appears, to reduce access time to any of several million records below 1/2 second and to provide for independent search by two or more read-write head units.

Three main searching schemes come to mind: keeping the sensing unit fixed and moving the storage medium (as in magnetic tapes, drums, and fundamentally in acoustic delay lines), keeping the storage medium relatively fixed and moving the sensing unit (as in two known random access memory systems and in electrostatic storage tubes) and having a 1:1 relationship between sensing units and storage positions with some form of switching arrangement to obtain selection (as in magnetic core memories). For very large volume memories, the third method looks prohibitively expensive using storage devices as known today. Storage at the atomic level has been discussed, and a type of sensing similar to electrostatic tube sensing or even magnetic core-type sensing may change the random access memory picture quite radically.

2) Machine Construction and Logic

a) Reduction of size and power. A central record machine for a large plant could become a sizeable machine requiring a large amount of electrical power and giving off considerable heat, using present day construction techniques. One promising solution to this problem appears to be the transistor, which is rapidly being improved to the point where it can be considered for such applications. In the EDPM discussed in the present paper, however, no great advantage of transistor over vacuum tubes is readily apparent.

b) Reliability. When one part of the human brain is damaged, its function can often be taken over (with a possible loss in efficiency) by another area of the brain. Such a procedure may well be considered for the central records machine of the future. The use of parallel-type components, each having its own functions to perform but capable of handling other functions as well, does not seem unreasonable.

Closely associated with this feature is that of self-checking. As has been mentioned, transmission over parallel paths is one method of improving reliability. Talks by nerve-net theorists point out that information in the human brain appears to be transmitted over parallel paths.

c) Non-numeric information representation. It has also been pointed out by nerve-net theorists that information probably is not stored in the human brain in the form of decimal or binary numbers [see 10]. To make the information in the computers less susceptible to noise, non-numeric representation methods may play an important part.

d) High speed printers. Closer to practical application, perhaps, are some of the developments in high speed printing. One major technique, called ferrography, has the computer record the printed information on a magnetically sensitized plate. Magnetic ink is sprayed on the plate and adheres to the magnetized areas; after a fixing treatment, the plate is used in normal printing fashion to run off multiple copies [11]. The question of whether such multiple copies will be accepted as legal equivalents of carbon copies has not yet been settled, to the author's knowledge.

e) Card-to-tape converters. Also closer to practical application is the development of high speed punched card-to-magnetic tape converters. This type of device probably will be most important during the transition phase in electronic data processing. Other developments, such as automatic readers and/or magnetic cards, may render the punched card largely obsolete in time.

VI. Summary

In brief, present day mathematical machines appear not too well suited for efficient data processing operations, but should do well on decision-making calculations.

Data processing requires good communication between the EDPM and the external memory units. Computing speed should be well balanced with external access time, and it appears that magnetic tape units will be very competitive with the newer random access memories in some applications. No general rule-of-thumb can be given; each firm would have to analyze its own operations and see what choice of units would best suit its needs.

This same type of analysis is undoubtedly being carried on by computer manufacturers who are interested in entering the commercial market. It is hoped that the reporting of this production control application will be of value to them in choosing their machine characteristics. Perhaps even more important, however, is the possibility that it will be of value to potential users of equipment. They are the ones who are ultimately responsible for analyzing their requirements and stating them in a language computer designers can understand.

Thus, this paper does not pretend to give a final or complete answer to EDPM design. It has attempted to point out some of the fundamental relationships and indicate possible solutions from a research point of view. Considerably more work will be needed in determining specifications for any industrial installation.

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10. Ibid. See pages 33, 43-44.

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